SEISMIC VELOCITIES OF THE TAGISH LAKE METEORITE: EXPLORING SAMPLE SIZE LIMITS FOR ELASTIC PROPERTY DETERMINATION.

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Introduction: Understanding the mechanical and elastic properties of rocks comprising asteroids is becoming of greater practical importance as more spacecraft interact with them (e.g. OSIRIS-REx, Hayabusa2, DART). However, knowledge of asteroid lithologies' physical properties is limited due to sample paucity and the resulting challenges that come with working with small samples. Measuring seismic velocities is one way to directly and indirectly (through relationships established with analog materials) explore elastic and strength properties, respectively, while minimizing use of available material. While sample preparation requires cutting, the seismic measurements are non-destructive.

Sample Size Limits: Seismic measurements record the elastic response of a solid such that minimum sample size to wavelength ratios are needed to avoid boundary effects; the theoretical minimum necessary sizes are defined by the wavelengths of the seismic waves used plus the rocks' p- and s-wave velocities [1]. With currently available ultrasonic transducers, a selection of frequencies may be made that allow measuring samples of a few mm in size (use of even higher frequencies is limited by increasing seismic wave attenuation). Required sample size is also determined by constituent grain sizes within the measured lithology (i.e. coarser lithologies require larger samples to allow representative results [1]).

Objective: The Tagish Lake meteorite is being used as a proxy for technique refinement for Bennu sample measurement. Tagish Lake is believed to have similar mineralogy [2] and intraclast porosity to asteroid Bennu's lithologies (and similar mechanical and elastic properties) and was recovered before being substantially disturbed by terrestrial weathering [3].

Sample selection pipeline. Bennu clasts will be "mapped" externally and internally by XCT (X-ray computed tomography) and SLS (structured light scanning) to select candidate clasts of suitable size and textures for measurement preparation. Nominally this will allow clast selection avoiding lithologic anomalies like particularly large inclusions or abundant cracking that would perturb results. These scans also allow planning cut orientation and measuring clast volume to confirm mass density. These procedures have been performed on three of the studied Tagish Lake meteorite clasts to validate work flows proceeding through seismic measurements on the resulting small slabs.

Sample Preparation: Irregularly shaped, porous, and friable clasts such as those of Tagish Lake are difficult to hold securely for cutting without damaging surfaces. Cutting two parallel surfaces is a further challenge if the sample must be removed and re-oriented between cuts. To ease this process a customizable sample holder strategy has been developed and implemented (Fig. 1). The custom holder uses 3D shape models of clasts to 3D print encapsulating mould segments with cutting guides incorporated. Obstructing convexities in the mould are removed so the clast can snugly drop into each holder segment. The outer holder surfaces are squared, making it easy to grip with conventional sample holder saw accessories; both a conventional low speed rotary saw and a wire saw have been used to dry cut Tagish Lake clasts achieving kerfs of ~0.15 mm. Sanding down to 2,000 grit achieves planarity and parallelism for the measurement surfaces.

Results and Conclusions: Table 1 lists seismic velocities measured on four Tagish Lake individual meteorites, including at least three visually distinct lithologies (Fig. 2). The three first-listed slabs went through the Bennu sample pipeline. The measurement uncertainty is smaller than the observed variation (the p and s wave velocity variations correlate) which reflects the lithologic variation in the brecciated meteorite. The smaller and thinner slabs are potentially more perturbable by environmental effects (e.g., absorbing atmospheric water) or suffering surface damage during cutting and sanding. The monitored "seating" stress pressing the transducers to the samples also slightly deforms them.

The measured Tagish Lake seismic velocities are low for extraterrestrial (or terrestrial) rocks reflecting their abundant phyllosilicate mineralogy and high intraclast porosity; these velocities will correspond to weak strengths and end-member elastic properties. The three visually distinct Tagish Lake lithologies showed relatively similar seismic velocities reflecting their similar intraclast porosities and composition.

Seismic measurements of Bennu samples will be most sensitive to variations in strength (due to mineralogy variation) and intraclast porosity possibly reflecting distinct lithologies. Any detected variations will constrain mission Sample Analysis Plan hypotheses [4].

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Sample ID	Inclusion Abundance	Bulk Density (g/cm^3)	Grain Density (g/cm^3)	Porosity (%)	Slab Mass (g)	Slab Thickness (mm)	Vp (m/s)	Vs (m/s)
EG-06	Low	1.61*	2.93	45.1*	0.225	3.63	1743	963
RC-11	Moderate	1.74*	2.95	41.0*	0.133	3.06	1613	835
ET-03	High	1.62*	2.91	44.5*	0.122	3.30	1531	819
PM-09a (1)	Moderate	1.60	2.87	44.4	0.270	4.79	1624	966
PM-09a (2)	Moderate	1.56	2.82	44.8	21.541	9.03	1273	778

* denotes values based upon SLS-derived volumes. XCT-derived volumes for the same clasts were ~3% smaller.

Table 1: Seismic velocities for five small slabs of four different Tagish Lake individuals. The first three samples may be relatively strong/competent sample volumes of their respective larger individuals as they were selected as relatively crack-free clasts from dozens of similar sized clasts (that had resulted from disaggregation of their parent meteorites after wet-dry cycles). Two pieces of the fourth individual (PM-09) were measured; the much larger piece had significantly lower velocities possibly reflecting unexposed cracks (other parts of this clast had numerous concentric shrinkage cracks). The second piece was a cuboid cut from a more intact part of this specimen.

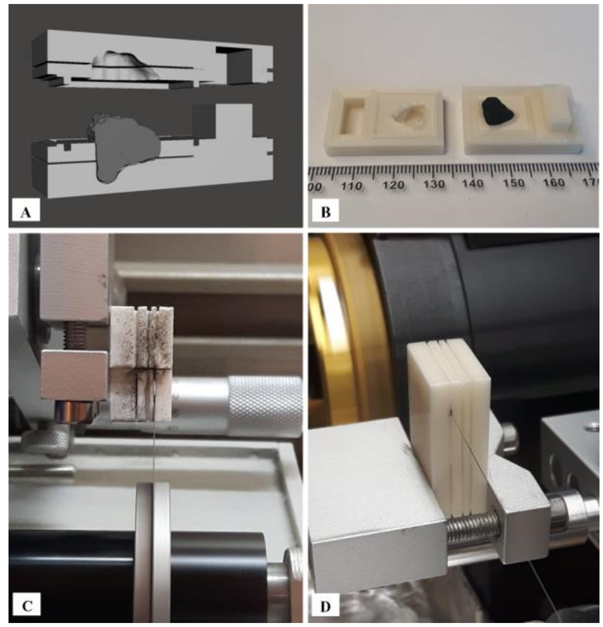

Figure 1: 3D-printed custom sample holder segments. A) Cross section through exploded view with sample loaded. B) EG-06 clast loaded in half of holder (mm scale). C) ET-03 sample cutting on Buehler low speed saw. D) EG-06 cutting on Well diamond wire saw.

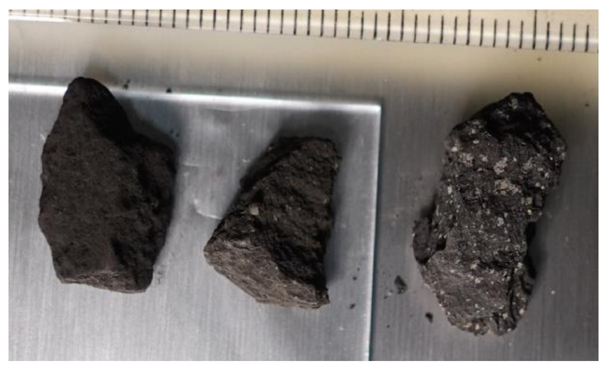

Figure 2: Example clasts (mm-scale divisions on ruler) from the three meteorite individuals of varying lithologies that went through the pipeline (note variation in inclusion abundance and reflectance). Left to right: EG-06, RC-11, ET-03. Note that EG-06 is much darker with few visible inclusions (the cause of the darkness is unknown) but XCT scanning revealed a similar internal texture.